Developing Framework to Constrain the Geometry of the Seismic Rupture Plane in Subduction Zones a priori

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1 INTRODUCTION

Many earthquake source inversions require knowledge of the geometry of the fault on which the earthquake occurred. Our knowledge of this surface is often uncertain, however, and as a result fault geometry misorientation can map into significant error in the final temporal and spatial slip patterns of these inversions. Relying solely on an initial hypocenter and CMT mechanism can be risky when establishing rupture characteristics needed for rapid tsunami and ground shaking estimates.

Here we attempt to improve the quality of fast finite-fault inversion results by combining several independent and complementary datasets to more accurately constrain the geometry of the seismic rupture plane of subducting slabs. Unlike previous analyses aimed at defining the general form of the plate interface, we require mechanisms and locations of the seismicity considered in our inversions to be consistent with their occurrence on the plate interface, by limiting events to those with well-constrained depths and with CMT solutions indicative of shallow-dip thrust faulting. We construct probability density functions about each location based on formal assumptions of their depth uncertainty and use these constraints to solve for the 'most likely' fault plane. In the case of large events (M > ~7.5), these planes can be used directly in new finite fault inversions. For smaller events, this method provides a quick analysis of the tectonic setting of an earthquake and a 'most likely' depth assuming the earthquake occurred on the subduction interface, which can be used as a check against other depth estimates produced at the NEIC.

2 DATA SELECTION AND FILTERING
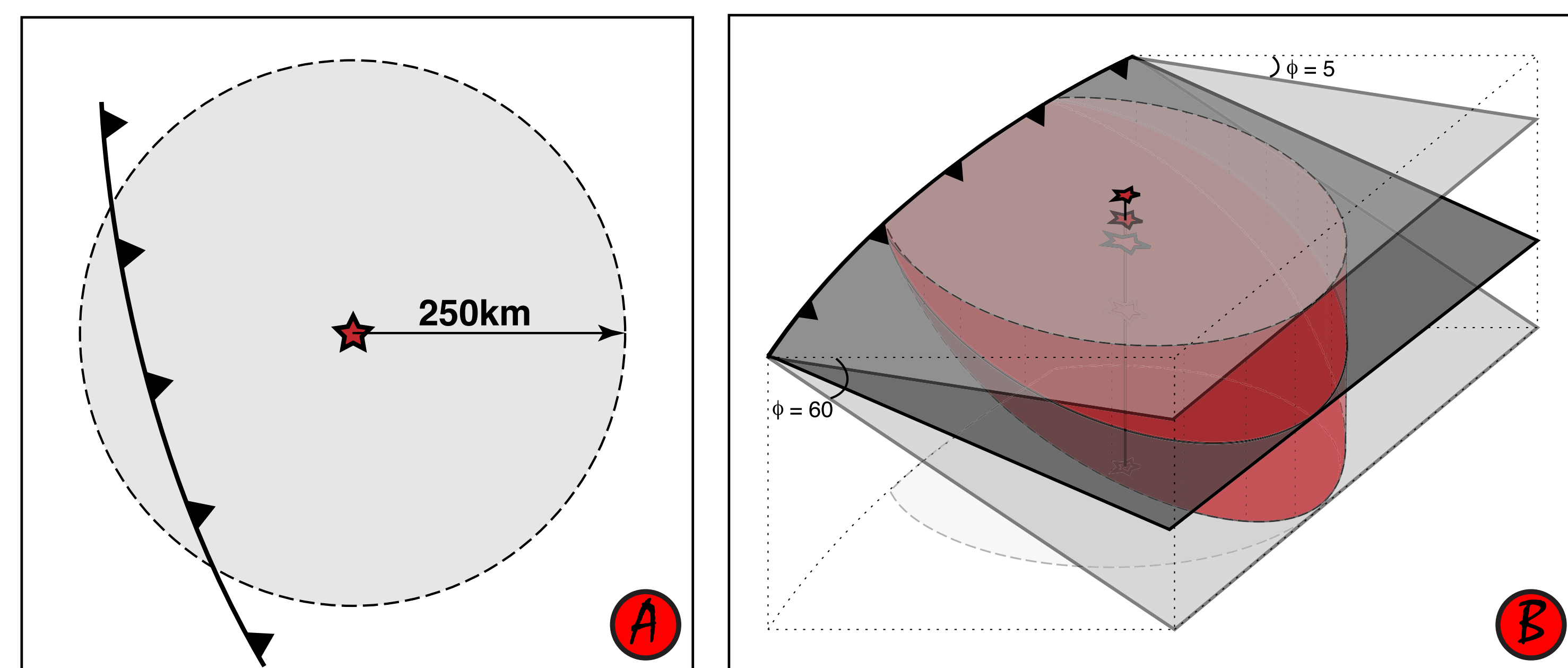
A: All well-constrained events from the gCMT catalog (using the criteria of Frohlich & Davis, 1990) and within 250km of the reference location (red star), whose mechanism matches that expected for a shallow-dipping thrust, are selected.

B: All events shallower than the equivalent depth of a plane dipping 5°, and deeper than the equivalent depth of a plane dipping 60°, at the same distance from the trench are removed from the catalog. This filter reduces the effects of upper-plate and deep earthquakes from the inversion. The red shaded region represents the remaining cylinder of events.
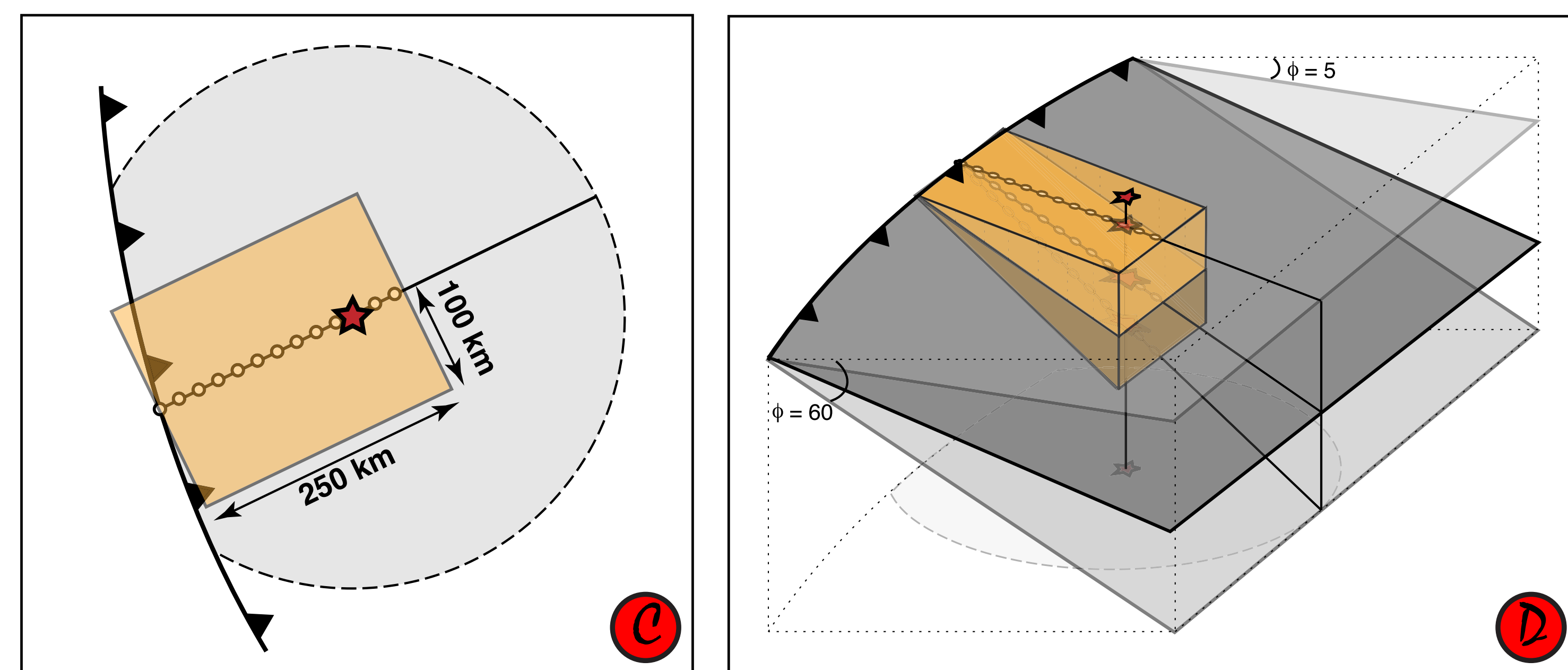
C: Using the remaining mechanisms, the average CMT strike is calculated. This angle is assumed to represent the approximate direction of subduction. From the reference location, we project back to the nearest point on the trench with this angle to establish the start point of our reference profile.

Using this trench location and angle, we construct the reference profile. All events greater than 100 km distance from this profile, in a direction perpendicular to that profile, are removed.

D: The remaining region of events is shaded here in orange, encompassing a rectangular region about the reference profile, between planes dipping at angles of 5° and 60°. For those events selected, we construct Normal Distribution Probability Density Functions about their reported depth, whose variance is based on reported depth error (EHB), or depth uncertainty w.r.t. the EHB catalog (NEIC & gCMT). All events are also weighted by magnitude, with larger events receiving higher weighting.

The dip of the subduction zone is computed in a direction perpendicular to the average strike of selected events by fitting an inclined plane through these PDFs following a maximum likelihood approach. We calculate the probability of the plane dipping at angles ranging from 5°-60°.
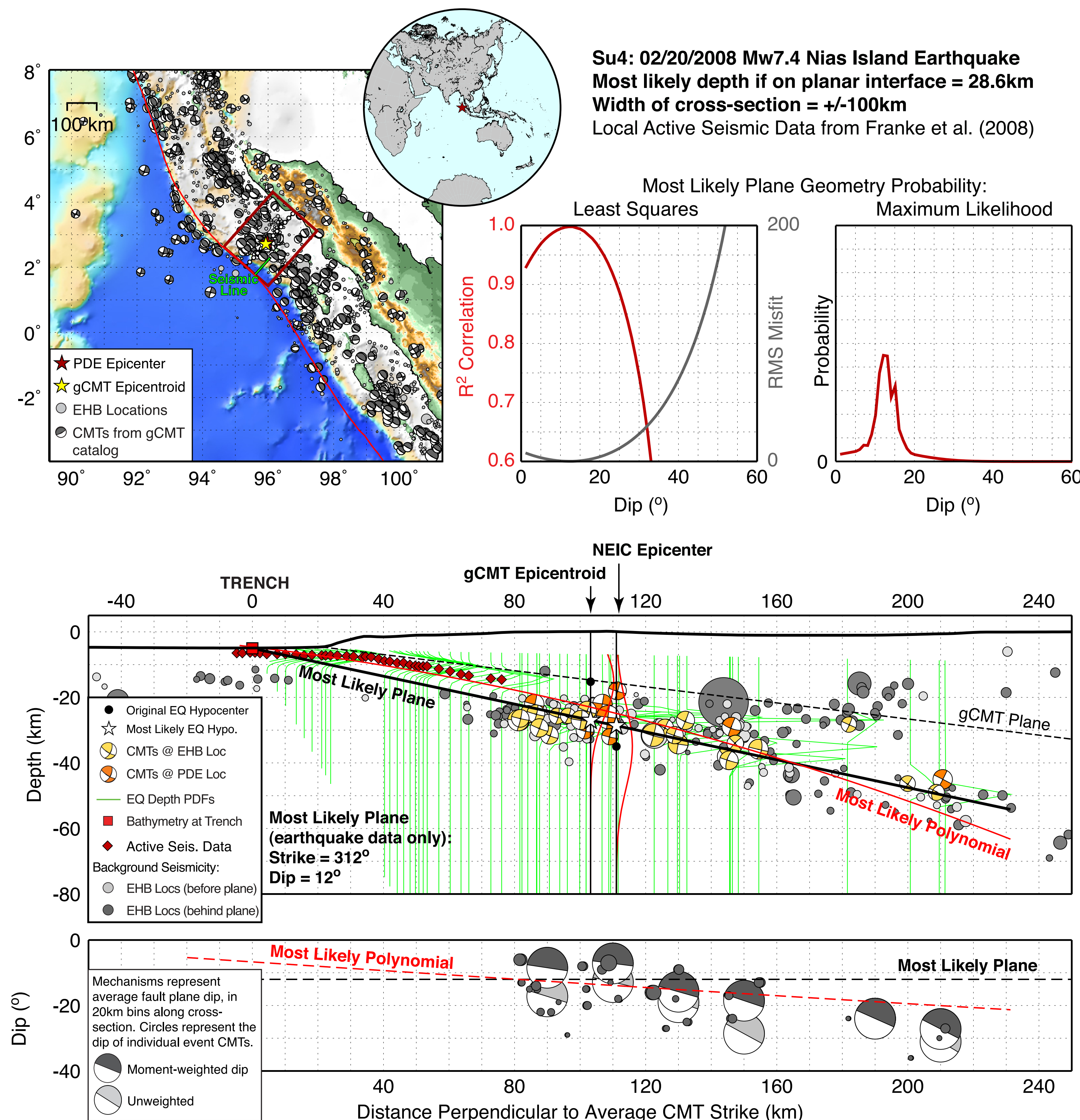
3 SUBDUCTION ZONE CONSTRAINT EXAMPLE - KAMCHATKA
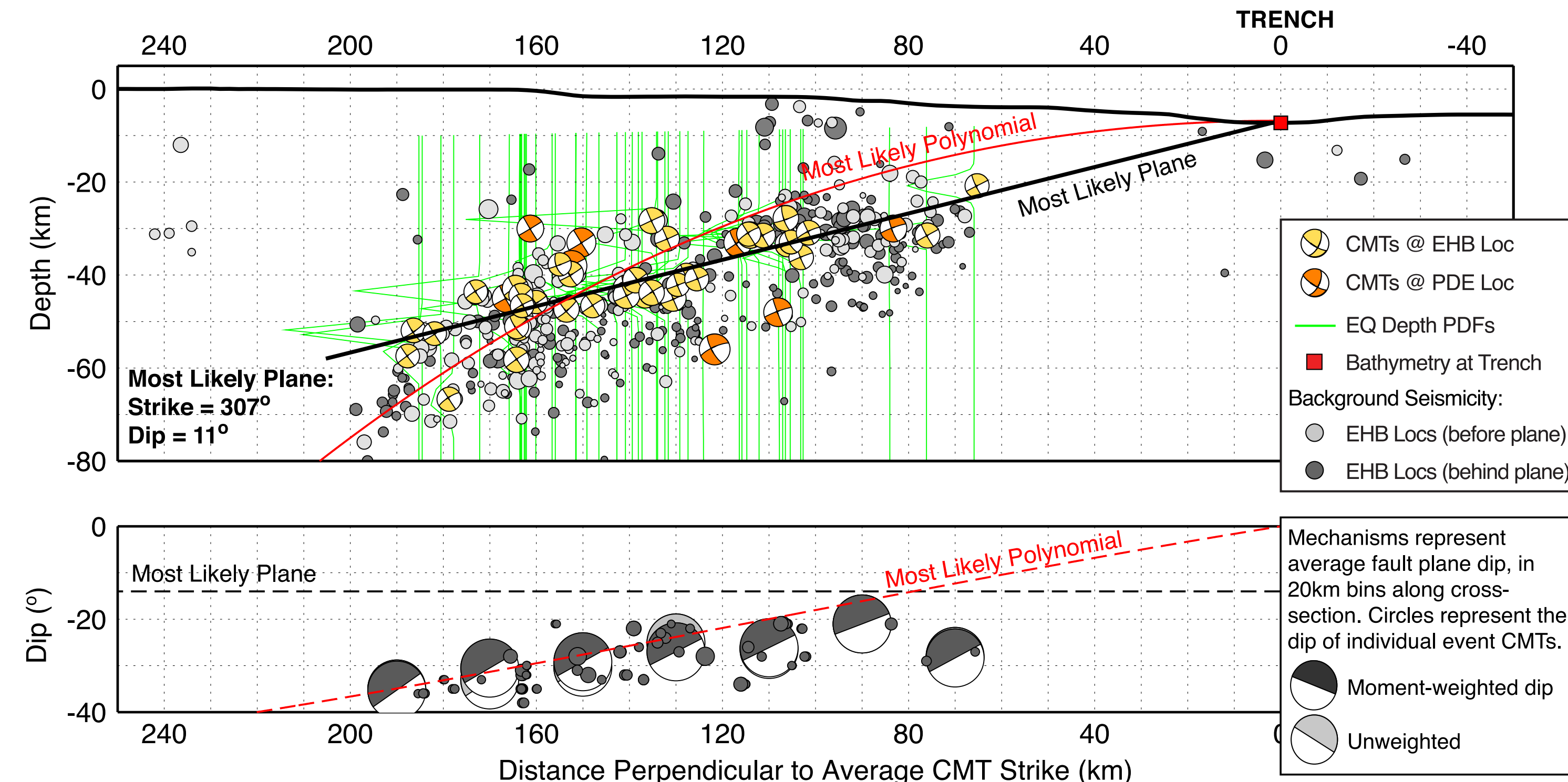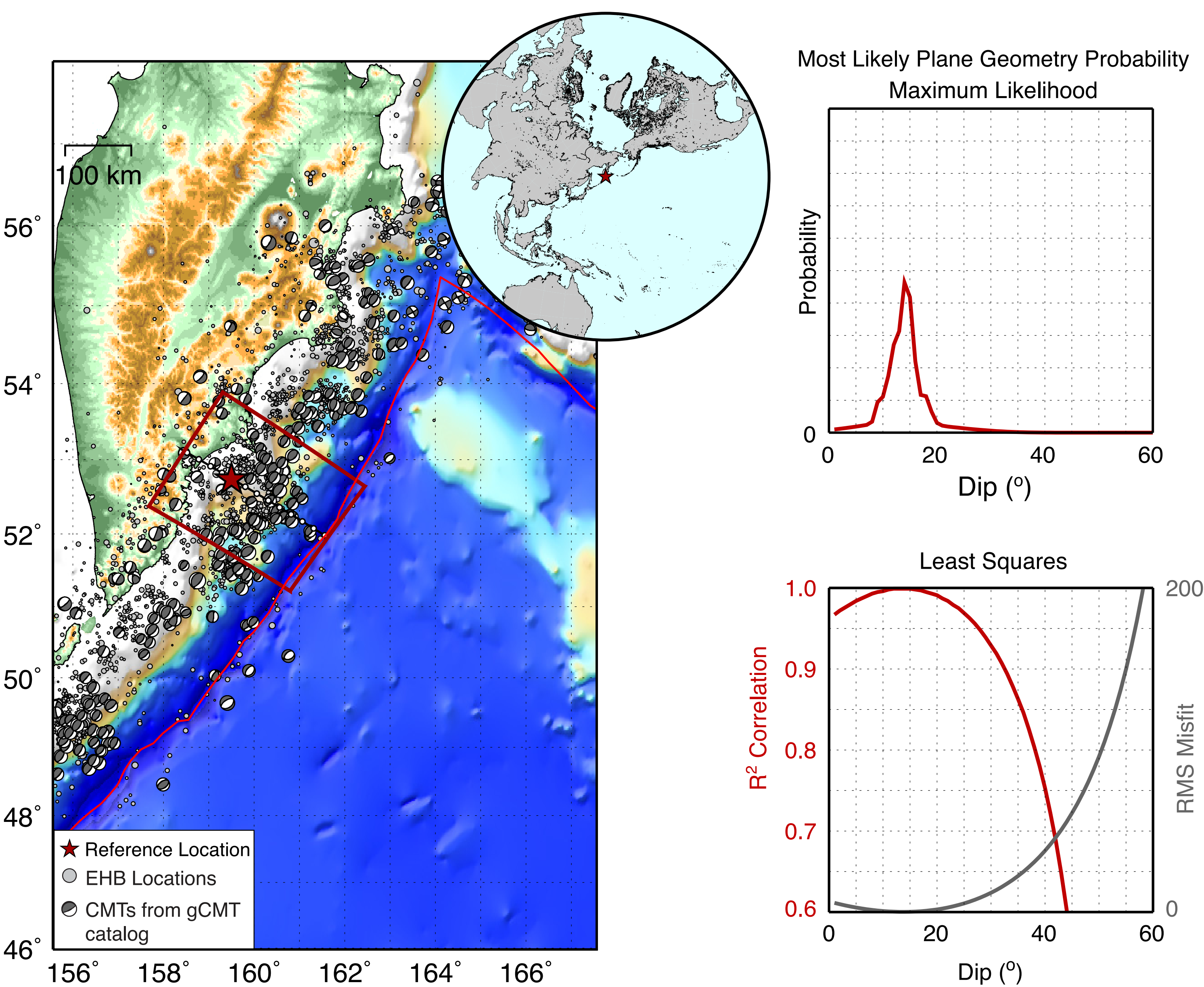
In the upper cross-section panel, interface geometry is calculated using the selected events and their respective PDFs. Selected events are shown by mechanisms from the gCMT catalog; yellow at EHB locations, and orange at NEIC PDE locations. Background seismicity is shown with gray circles; these events are either too small to have CMT solutions, or did not match the filtering criteria.

The lower panel shows a comparison between the dip of the best-fitting interface (planar and polynomial fits) with the individual dips of CMT mechanisms along the section. In general, the dip of the shallow plane in the best-fitting double couple of the CMT solution is steeper than is the actual subduction interface.

4 INTEGRATING DATA SETS TO IMPROVE INTERFACE SAMPLING

Su4: 02/20/2008 Mw7.4 Nias Island Earthquake
Most likely depth if on planar interface = 28.6km
Width of cross-section = +/-100km
Local Active Seismic Data from Franke et al. (2008)

Per: 08/15/2007 Mw8.0 Peru Earthquake
Most likely depth if on planar interface = 50.3km
Width of cross-section = +/-100km
Local Active Seismic Data from Krabbenhoft et al. (2004)

Special thanks to Katie Keranen, Steve Kirby and Dave Scholl and USGS Menlo Park for active source data and interpretation.

5 DIP DISCREPANCIES - INTERFACE DIP vs. CMT DIP

At the majority of locations we have analyzed for subduction interface geometry, a comparison between the dip of the most-likely plane (or polynomial) and the dip of the shallow plane of the best-fitting double-couple of individual CMTs along the length of the cross-section shows significant scatter. For planar geometries (and to some extent the polynomial fits also), this scatter is biased towards over-steepened CMT solutions.
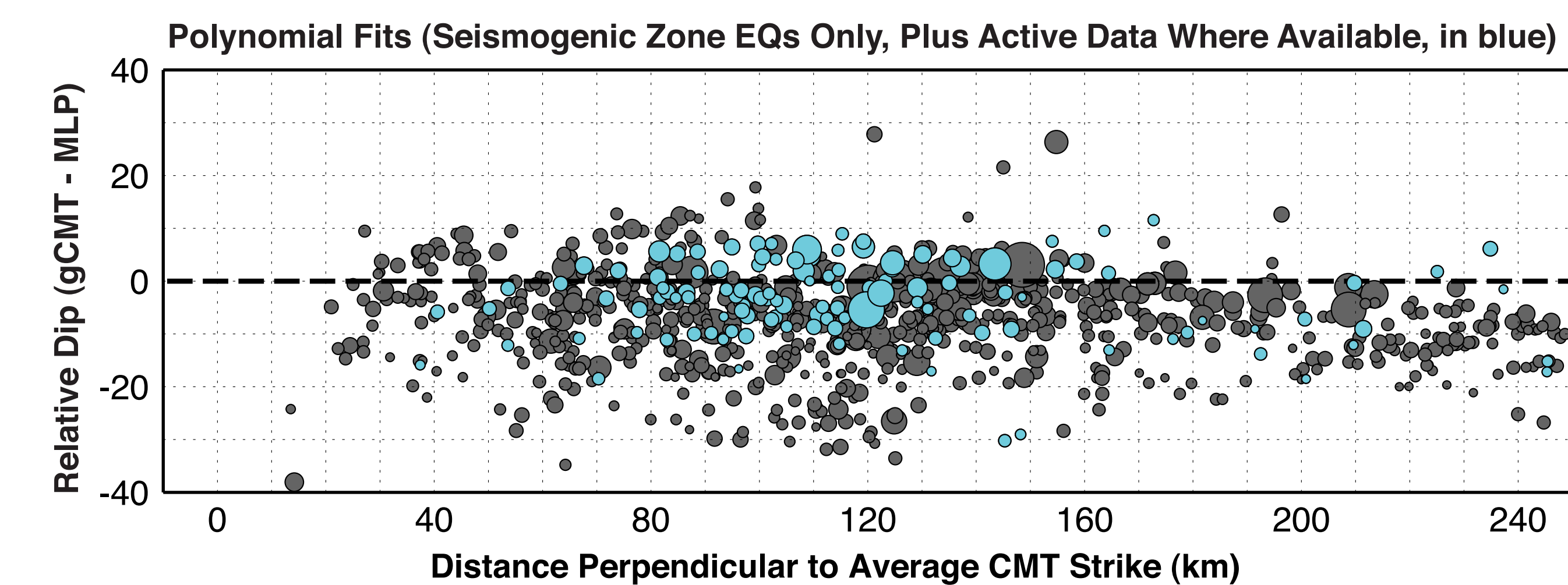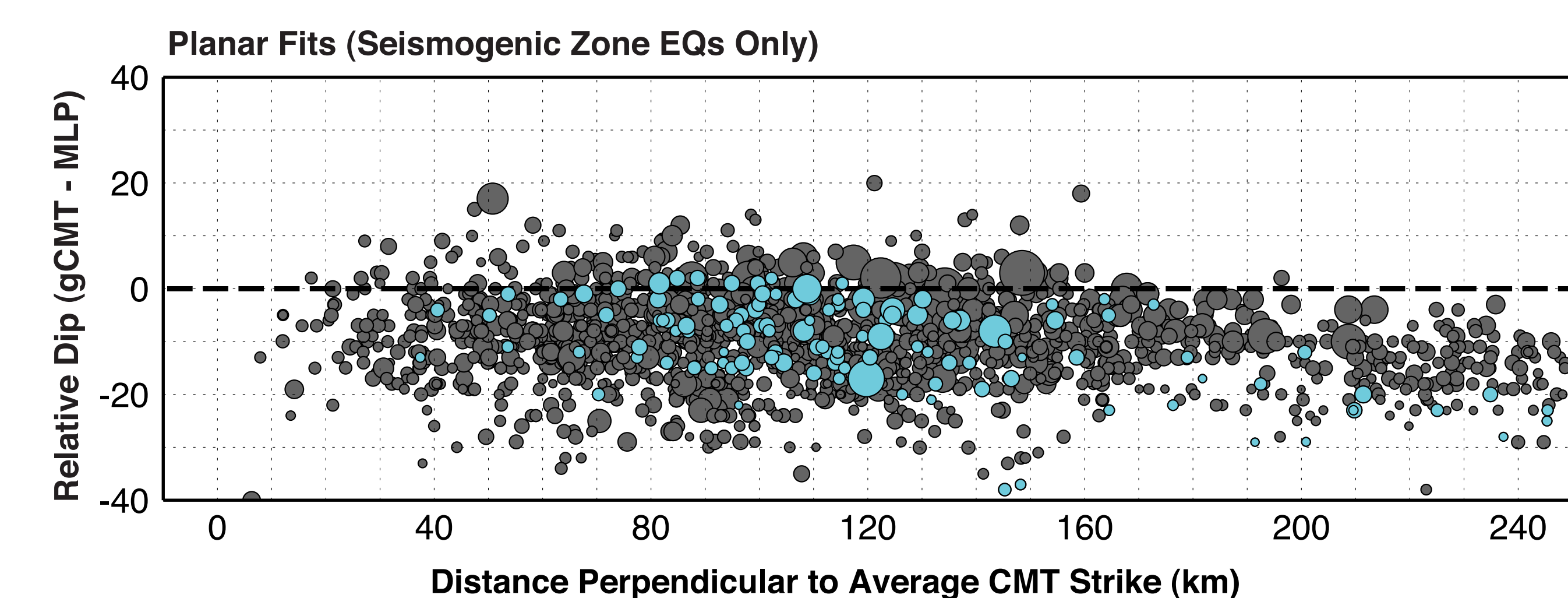
Areas where we have the additional constraint of local active seismic data are plotted in blue. In all locations, only the earthquake data were used to invert for the most likely planar geometry. Polynomial fits include local data if available.

What causes this scatter/bias? Is the bias real?

- Uncertainties/errors in CMT inversions (e.g. moment vs. dip trade-off)?
- Bias in CMT solutions caused by the use of 1D velocity models?
- Some bias can be accounted for by slab-rollover; i.e. non-planar geometries. BUT...some bias and significant scatter still remains in polynomial fit comparison.

- REAL SIGNAL? e.g. evidence for (small) ruptures on structures close to and at (generally) higher angles than the main thrust interface?

6 IMPLICATIONS FOR FINITE FAULT MODELING

Modifying the plane on which we compute our finite fault inversions may have significant implications for the location and amplitude of slip.

Model 1 - Original Inversion with CMT Plane

Model 2 - Modified Inversion with MLP
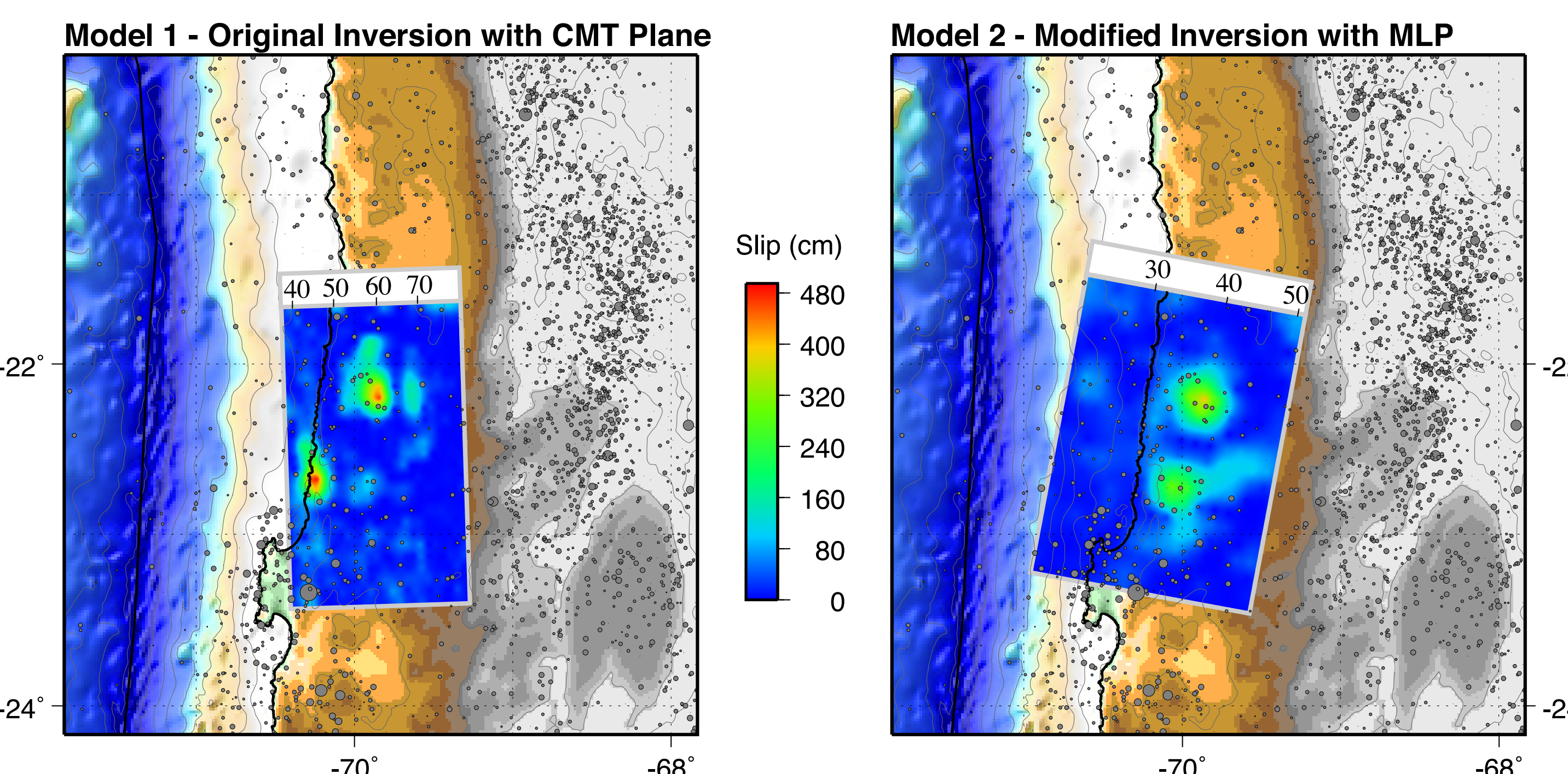
Such results become significant for any subsequent models that rely on the depth and distribution of slip:

- Ground shaking estimates (leading to rapid response decisions)
- Tsunami modeling & predictions

FUTURE DIRECTIONS:

As we improve our data coverage of the subducting plate, polynomial fits become more viable and can accurately capture true interface geometry.

In the future, these profiles will be explicitly merged with current Finite Fault Modeling algorithms, allowing us to invert over a 'mesh' geometry rather than one or more planar interfaces. Such a step facilitates finite fault models that more accurately model slip on the undulating subduction interface.

Such 3D surfaces will form the basis of SLAB1.0, a global model of the interface geometry of subduction zones. This collaborative project is currently underway between the NEIC and researchers at USGS Menlo Park.